

VU Research Portal

The influence of task variation on manifestation of muscle fatigue is ambiguous - a literature review

Luger, T.; Bosch, T.; Veeger, H.E.J.; de Looze, M.P.

published in

Ergonomics

2014

DOI (link to publisher)

[10.1080/00140139.2014.885088](https://doi.org/10.1080/00140139.2014.885088)

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Luger, T., Bosch, T., Veeger, H. E. J., & de Looze, M. P. (2014). The influence of task variation on manifestation of muscle fatigue is ambiguous - a literature review. *Ergonomics*, 57(2), 162-174.
<https://doi.org/10.1080/00140139.2014.885088>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl



Ergonomics

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/terg20>

The influence of task variation on manifestation of fatigue is ambiguous - a literature review

Tessy Luger^{abc}, Tim Bosch^{bc}, Dirkjan Veeger^a & Michiel de Looze^{ab}

^a MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, Van Der Boechorststraat 9, 1081 BT, Amsterdam, The Netherlands

^b TNO Quality of Life, Polarisavenue 151, 2132 JJ, Hoofddorp, The Netherlands

^c Body@Work, Research Centre on Physical Activity, Work and Health, TNO-VU University Medical Centre, Amsterdam, The Netherlands

Published online: 19 Feb 2014.

To cite this article: Tessy Luger, Tim Bosch, Dirkjan Veeger & Michiel de Looze, Ergonomics (2014): The influence of task variation on manifestation of fatigue is ambiguous - a literature review, Ergonomics, DOI: [10.1080/00140139.2014.885088](https://doi.org/10.1080/00140139.2014.885088)

To link to this article: <http://dx.doi.org/10.1080/00140139.2014.885088>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

The influence of task variation on manifestation of fatigue is ambiguous – a literature review

Tessy Luger^{a,b,c,*}, Tim Bosch^{b,c,1}, Dirkjan Veeger^{a,2} and Michiel de Looze^{a,b,3}

^aMOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, Van Der Boechorststraat 9, 1081 BT, Amsterdam, The Netherlands; ^bTNO Quality of Life, Polarisavenue 151, 2132 JJ, Hoofddorp, The Netherlands; ^cBody@Work, Research Centre on Physical Activity, Work and Health, TNO-VU University Medical Centre, Amsterdam, The Netherlands

(Received 29 October 2013; accepted 9 January 2014)

Task variation has been proposed to reduce shoulder fatigue resulting from repetitive hand–arm tasks. This review analyses the effect of task variation, both ‘temporal (i.e. change of work–rest ratio)’ and ‘activity (i.e. job rotation)’ variation, on physiological responses, endurance time (ET) and subjective feelings. Pubmed was searched and complemented with references from selected articles, resulting in 17 articles. Temporal variation had some positive effects on the objective parameters, as blood pressure decreased and ET increased, and on the subjective feelings, as perceived discomfort decreased. The observed findings of activity variation showed both positive and negative effects of increased activity variation, while hardly any effects were found on electromyography manifestations of fatigue. In conclusion, the evidence for positive effects of increasing the level of variation is scarce. The number of studies on variation is limited, while in most studies the findings were not controlled for the amount or intensity of work.

Practitioner Summary: Some laboratory-controlled studies showed some positive effects of increasing temporal variation, providing limited support for introducing frequent interruptions in work. Activity variation showed ambiguous effects, meaning there is no evidence for practical implication. In practice, however, other positive effects of activity variation may occur, for example job enrichment and increased motivation.

Keywords: variation; fatigue; shoulder; electromyography

1. Introduction

Work-related musculoskeletal disorders are a major problem for the workers and the society and comprise a wide range of inflammatory and degenerative disorders. The shoulder is among the most common sites of musculoskeletal complaints with prevalence estimates ranging between 5% and 47% (Luime et al. 2004; van der Heijden 1999). Incidence estimates of sick leave due to shoulder pain that were reported to the general practitioner varied from 18–29% for 4–6 years (Grooten et al. 2004) to about 30% for 6 months (Kuijpers et al. 2006).

The aetiology of shoulder disorders is not fully understood. Westgaard and Winkel (1996) introduced a model in which external exposure leads to internal exposure and acute physiological responses and in the long term to shoulder complaints and disorders. Several factors of external exposure have been identified to increase the risk of shoulder complaints in epidemiological research. Among these are awkward body postures (e.g. arm elevation in overhead work), monotonous or repetitive work and hand–arm work in particular, upper extremity vibrations and high force exertion (Andersen et al. 2002; van Rijn et al. 2010).

Repetitiveness and monotonous work are very common nowadays due to the automation of work processes in many occupations (Mathiassen 2006). Since the work intensity in this type of work is often low, the work can be sustained for longer periods of time without interspersing breaks. Monotonous work implies continuous loading of internal structures in the shoulder region, which limits the opportunities for these structures to recover. The main internal structures in this respect are the stabilising muscles of the scapula (Szeto, Straker, and O’Sullivan 2005).

As an employer, one might approach the problem of continuous work by the introduction of extra rest breaks. Additional breaks have been shown to effectively reduce the development of fatigue (Hagberg and Sundelin 1986; Henning et al. 1997; Samani et al. 2009). Several studies have also shown that introducing active breaks might be even more effective (Henning et al. 1997), but not everyone agrees (van den Heuvel et al. 2003). However, from the perspective of productivity, such an intervention (breaks) is not always possible or desirable.

Variation in the task, however, might be an alternative method to tackle potential precursors of shoulder complaints, such as fatigue and subjective discomfort. In general, variation can be defined as the change in exposure to the workload across time (Mathiassen 2006). One might distinguish several types of task variation. The first type of variation is ‘temporal

*Corresponding author. Email: t.luger@vu.nl

variation' in which the type of activity and the amount of work do not change, only their pattern over time (e.g. a change in cycle time (CT) with a constant duty cycle (DC)). Another type of variation is 'activity variation' in which the type of activity changes in terms of force pattern or movement pattern (e.g. task rotation). In practice, activity variation (e.g. by job rotation) is often accompanied with variations in the temporal pattern.

In this review, we focus on laboratory and field studies on monotonous repetitive hand–arm tasks, where the levels of temporal variation or activity variation have been varied across conditions. We specifically focus on hand–arm tasks because the shoulder is explicitly involved in this. We did not include studies on the effects of the introduction of additional rest breaks in continuous work. The main objective is to analyse the effect of different amounts of variation in the task on physiological responses (e.g. muscle activation, blood oxygenation), endurance time (ET) and subjective responses (e.g. local perceived discomfort). We include those kinds of responses that potentially contribute to the aetiology of work-related shoulder complaints.

2. Methods

This review was based on the identified literature from an electronic search in Pubmed. We used the following keywords to gather relevant primary studies: (1) 'redesign' or 'job enlargement' or 'job enrichment' or 'task rotation' or 'redistribution' or 'reorganization' or 'reorganisation' or 'organisational change' or 'rationalisation' or 'job rotation' or 'pace' or 'pacing' or 'duty cycle' or 'cycle time' or 'rationalization' or 'pause' or 'pauses' or 'break' or 'breaks' or 'work-rest' or 'work/rest' or 'work rest' or 'repetition' or 'repetitions' or 'monotonous' or 'monotony' or 'static' or 'dynamic' or 'task order' or 'variation' or 'variability' or 'intermittent' and (2) 'shoulder' or 'shoulders' or 'Trapezius' or 'Deltoid' or 'scapula' or 'upper extremity' and (3) 'EMG' or 'electromyography' or 'near infrared spectroscopy' or 'NIRS' or 'microdialysis' or 'Borg' or 'VAS' or 'RPE' or 'RPD' or 'discomfort' or 'exertion' or 'force' or 'pain' or 'fatigue' and not (4) 'athlete' or 'hemiplegia' or 'arthroplasty' or 'dyskinesias' or 'Parkinson' or 'stroke' or 'carpal tunnel syndrome'. Additional limitations were specified, including language being only 'English', the date of publication in the period '1990–June 2013' and the study population consisting of 'humans'.

The resulting references from this search were first screened on the basis of their title and abstract. When the title and abstract did not provide sufficient information, the full text was screened. Based on this selection, the studies apparently fulfilling the inclusion criteria, which are mentioned later, were selected for further study. This selection was supplemented with articles that were cited in the studies found and their references. Finally, personal databases of the authors were searched for additions.

Included articles had to describe experimental studies in the lab or in the field, including intervention studies, comparing different levels of variation. Only studies on the shoulder, considering the objective and subjective responses in that area, were included. Articles were included only when the study involved occupational hand–arm tasks, except computer tasks. For inclusion, the minimal task duration was 30 min, based on the belief that (subjective) fatigue needs time to develop. In advance, we excluded studies focussing on athletes or patients suffering from diseases as mentioned earlier in the fourth group of keywords.

3. Results

The initial search led to 3436 hits in Pubmed. Screening of the titles resulted in the exclusion of 3209 articles. Further judgement of the abstracts led to exclusion of 182 more articles. The main reasons for exclusion were no variation (158 articles), the interested body region not being the shoulder (10 articles), the study population consisting of patients only (six articles), the task either containing computer work (four articles) or being too short (two articles), or the study focusing on sports performance (two articles).

Applying the selection criteria on the full text of the remaining 45 articles led to the exclusion of 36 more articles. In these articles, no variation was applied (20 articles), the task duration did not meet the 30-minute criterion (six articles), the body region of interest was either the forearm, hand or finger (four articles), the assessment focused on the task duration without focussing on the shoulder (two articles), the task contained computer work (two articles), no full text of the article was available (one article) or the same study was described in two articles (one article). The remaining nine articles were scanned for citations and references, which resulted in the addition of six extra articles. Finally, two articles from the authors' personal databases were added. The resulting 17 articles are presented in [Table 1](#) (temporal variation) and [Table 2](#) (activity variation).

The second last column in [Tables 1 and 2](#) gives the mean difference (MD) between conditions with associated *p*-values to show whether the difference was significant or not. The EMG parameters are grouped by parentheses, because we considered a fatigue effect on EMG only when both its frequency and amplitude changed significantly. The arrows in this column are only displayed for significant differences. In the last column of [Tables 1 and 2](#), we have summarised the overall

Table 1. Summary of selected studies on 'Temporal variation'.

Study	Design	Population	Task (duration)	Conditions	Response variables (muscle/body part ^a) and outcomes ^b	Conclusion	
						O	S
Iridiastadi and Nussbaum (2006)	Lab study	Students $N = 48$	Static isometric–isotonic shoulder abductions (20–60 min)	# 1–4: CT = 166 s, varying levels of intensity and DC across conditions (less variation) # 5–8: CT = 34 s, varying levels of intensity and DC across conditions (more variation)	EMG RMS MeD (MD = -0.06 %/min; ns)	o	o
					EMG MnPF MeD (MD = $+0.30$ %/min; $p < 0.05$) ↑		
					EMG MdPF MeD (MD = $+0.33$ %/min; $p < 0.05$) ↑		
					MVE (MD = -0.02 %/min; ns)		
					ET (MD = $+3.6$ min; ns)		
Mathiassen (1993)	Lab study	Subjects with sedentary occupation $N = 6$	Isometric shoulder abduction until exhaustion (60 min)	# 1: CT = 360 s, DC = 0.83 (less variation) # 2: CT = 60 s, DC = 0.83 (medium variation) # 3: CT = 10 s, DC = 0.83 (most variation)	RPD (MD = -0.05 ; ns)	o	o
					EMG RMS UT (MD = n.d.; ns)		
					EMG ZC rate UT (MD = n.d.; ns)		
					MVC (MD = n.d.; ns)		
					1-min test contraction (MD = n.d.; ns)		
					HR (MD = n.d.; ns)		
					BP (MD = -6.6 % mmHg; $p = 0.02$) ↓		
					Lactate (MD = $+0.03$ mmol/L; ns)		
					K ⁺ (MD = n.d.; ns)		
					ET (MD = $+16.9$ min; $p < 0.01$) ↑		
Yasserli and Nussbaum (2007)	Lab study	General population $N = 48$	Sub-maximal intermittent isokinetic shoulder abductions (≤ 60 min)	# 1: CT = 40 s, DC = 0.50 (less variation) # 2: CT = 20 s, DC = 0.50 (more variation)	RPF (MD = -2.3 ; ns)	o	+
					EMG RMS MeD (MD = -0.17 %/min; $p < 0.05$) ↓		
					EMG MnPF MeD (MD = -0.17 %/min; $p < 0.05$) ↓		
					EMG MdPF MeD (MD = -0.17 %/min; $p < 0.05$) ↓		
					Rate of MVIC decline (MD = -0.24 %/min; $p < 0.05$) ↓		
					ET (MD = $+8.3$ min; $p < 0.05$) ↓		
					Rate of RPD increase (MD = -0.03 unit/min; $p < 0.05$) ↓		

Note: The conclusion in the last column is based on the significant outcomes and divided into two groups of parameters: objective (O) and subjective (S). The symbols indicate whether the particular group of parameters was predominantly positively ('+') or not significantly or equally positively and negatively ('o') affected by more temporal variation.

Abbreviations: CT, cycle time; DC, duty cycle; EMG amplitude is expressed as the root mean square (RMS); EMG frequency is expressed as the mean (MnPF) or median (MdPF) power frequency; MVE, maximum voluntary exertion; ET, endurance time; RPD, rating of perceived discomfort; ZC, zero crossing; MVC, maximum voluntary contraction; HR, heart rate; BP, blood pressure; K⁺, potassium; RPF, rating of perceived fatigue; MVIC, maximum voluntary isokinetic contraction.

^aMuscles are specified between brackets right after the response variable: MeD, M. Deltoid Medialis; UT, M. Trapezius Descendens.

^bAll results with the mean difference (MD) and associated p -value are presented. When the MD was not given in the original article, it is noted as 'n.d.' (not defined); significance levels higher than .05 are noted as 'ns' (not significant).

Study	Design (variation subtype)	Population	Task (duration)	Conditions	Response variables (muscle/body part ^a) and outcomes ^b	O	S	Conclusion
Arvidsson et al. (2012)	Field study (rationalisation)	Male meat cutters $N = 5$ (split-carcase) $N = 10$ (sixth-part) $N = 5$ (line-production)	Meat cutting: lifting, shifting, and deboning (139–313 min)	# 1 (split-carcase system; pre-rationalisation): lifting and shifting meat parts, no rotation across workstations (less variation) # 2 (sixth-part system): deboning shoulders, hams or middle parts, rotation across workstations on different days (medium variation) # 3 (line-production): lifting, cutting and trimming, six rotations across workstations per day (more variation)	Muscular load rest TR: #1 vs. #2–3 (MD = +0.45 %time; ns) Muscular load activity 50th% TR: #1 vs. #2 (MD = –4.3 %MVE; $p < 0.05$) ↓ Muscular load activity 50th% TR: #1 vs. #3 (MD = –2.8 %MVE; ns) Muscular load activity 90th% TR: #1 vs. #2 (MD = –9 %MVE; $p < 0.05$) ↓ Muscular load activity 90th% TR: #1 vs. #3 (MD = –5% MVE; ns)		o	n.a.
Balogh, Ohlsson, and Hansson (2006)	Field study (rationalisation)	Operators $N = 152$	Process wooden boards for parquet flooring (about 30 min)	# 1: manual line, 4 work stations, rotation across work station every 0.5 h (more variation) # 2: semi-automated line, 6 work stations, rotation across work stations every 0.5 h (more variation) # 3: automated line, 1 work station, no rotation across work stations (less variation)	EMG rest TR: #3 vs. #1 (MD = –2 %time; ns) EMG rest TR: #3 vs. #2 (MD = +28 %time; $p < 0.05$) ↑ EMG APDF TR 50th%: #3 vs. #1–2 (MD = –1.7; ns) EMG APDF TR 90th%: #3 vs. #1–2 (MD = –3.7; ns)		o	n.a.
Bao, Mathiasen, and Winkel (1996)	Field study (rationalisation)	Assembly workers $N = 23$ (pre) $N = 13$ (post)	Assembling sewing machines (30 min or longer)	# 1 (OLD line, pre-rationalisation): longer uninterrupted periods of work, more rotation across work stations (more variation) # 2 (NEW line, post-rationalisation): shorter uninterrupted periods of work, less rotation across work stations (less variation)	EMG APDF R. UT (L. UT (R. INF (MD = +19 %; ns) EMG EVA R. UT (MD = –2.2 %; ns) EMG EVA L. UT and R. INF (MD = +9.3 %; ns) Average HR (MD = +1 bpm; ns)		o	n.a.

Christmann, Friden, and Sollerman (1999)	Field study (rationalisation)	Assembly workers $N = 17$ (pre) $N = 12$ (post)	Assembling tasks to produce handles for doors and windows (not clearly specified)	# 1 (pre-rationalisation): repetitive and monotonous assembly tasks with a cycle time of a few seconds to a couple of minutes; less task rotation (less variation) # 2 (post-rationalisation): departments split into independent product workshops, creating more varying object and motor skills without affecting assembly operations; more task rotation (more variation)	Prevalence of MSPD (MD = +4% employees; $p < 0.05$) ↑	—	n.a.	
	Lab study (rotation)	General population $N = 12$	Isometric shoulder abductions matching a fixed target moment (60 min)	# 1: no rotation [low exertion (L)] (less variation) # 2: no rotation [high exertion (H)] (less variation) # 3: one rotation (L → H) (medium variation) # 4: one rotation (H → L) (medium variation) # 5: three rotations (L → H → L → H) (most variation) # 6: three rotations (H → L → H → L) (most variation)	EMG ARV R, MeD (#1 vs. #3–6: MD = +0.31 %RVE; $p < 0.001$) ↑ EMG ARV R, MeD (#2 vs. #3–6: MD = −0.28 %RVE; $p < 0.001$) ↓ EMG ARV R, MeD (#3–4 vs. #5–6: MD = −0.04 %RVE; ns) EMG MnPF R, MeD (#1–2 vs. #3–6: MD = +0.02 %RVE; ns) EMG MnPF R, MeD (#3–4 vs. #5–6: MD = 0 %RVE; ns) EMG DSI R, MeD (#1 vs. #3–6: MD = +0.08 %RVE; ns) EMG DSI R, MeD (#2 vs. #3–6: MD = −0.13 %RVE; ns) EMG DSI R, MeD (#3–4 vs. #5–6: MD = −0.04 %RVE; ns) Mean RPD (#1 vs. #3–6: MD = +0.47; $p = 0.0038$) ↑ Mean RPD (#2 vs. #3–6: MD = −0.64; $p < 0.001$) ↓ Mean RPD (#3–4 vs. #5–6: MD = n.d.; ns) Peak RPD (#1 vs. #3–6: MD = +1.40; $p < 0.001$) ↑ Peak RPD (#2 vs. #3–6: MD = −0.99; $p < 0.001$) ↓ Peak RPD (#3–4 vs. #5–6: MD = +0.21; ns)	0	0	0
Keir, Sanei, and Holmes (2011)	Lab study (rotation)	University students $N = 10$	Lifting a 12 kg box from 0.55 m to waist and back, 6 p/min; gripping at 20% MVC, 6 p/min (30 min)	# 1: (LL) lifting (30 min) (less variation) # 2: (GG) gripping (30 min) (less variation) # 3: (LG) lifting (15 min) – gripping (15 min) (more variation) # 4: (GL) gripping (15 min) – lifting (15 min) (more variation)	EMG APDF AD, TR 10th%: #1 vs. #3–4 (MD = −0.8 %MVE; ns) EMG APDF AD, TR 10th%: #2 vs. #3–4 (MD = +0.5 %MVE; ns) EMG APDF AD, TR 50th%: #1 vs. #3–4 (MD = −3.5 %MVE; ns) EMG APDF AD, TR 50th%: #2 vs. #3–4 (MD = +7.5 %MVE; ns) EMG APDF AD, TR 90th%: #1 vs. #3–4 (MD = −3.5 %MVE; ns) EMG APDF AD, TR 90th%: #2 vs. #3–4 (MD = +7.5 %MVE; ns) EMG APDF AD, TR 99th%: #1 vs. #3–4 (MD = −2.4 %MVE; ns) EMG APDF AD, TR 99th%: #2 vs. #3–4 (MD = +16.7 %MVE; ns) EMG gaps: #1 vs. #3–4 (MD = n.d.; ns) EMG gaps: #2 vs. #3–4 (MD = +6 %MVE, ns) RPE: #1 vs. #3–4 (MD = −0.5; $p < 0.05$) ↓ RPE: #2 vs. #3–4 (MD = +0.8; $p < 0.05$) ↑	0	0	0
Kuijer, Visser and Kemper (1999)	Field study (rotation)	Refuse collectors $N = 16$	Refuse collecting (a), street sweeping (b) and driving (c) (working day)	# 1: no rotation (work station a or b) (less variation) # 2: rotation (across work stations a and b) (more variation) # 3: rotation (across work stations b and c) (more variation)	%HRR: #1a vs. #2–3 (MD = −23.6; $p < 0.05$) ↓ %HRR: #1b vs. #2 (MD = +1.2; ns) %HRR: #1b vs. #3 (MD = −21.1; ns) RPE: #1a vs. #2–3 (MD = −38.4; $p < 0.05$) ↓ RPE: #1b vs. #2–3 (MD = −12.4; ns) RPF: #1a vs. #2–3 (MD = −1.6; $p < 0.05$) ↓	+	+	+

(continued)

Table 2 – continued.

Study	Design (variation subtype)	Population	Task (duration)	Conditions	Response variables (muscle/body part ^a) and outcomes ^b	Conclusion	
						O	S
Kuijer et al. (2004)	Field study (rotation)	Refuse collectors $N = 12$	Refuse collecting (a) and truck driving (b) (working day)	# 1: no rotation (work station a or b) (less variation) # 2: rotation (across work stations a and b, ratio 2:1) (more variation)	HR: #1a vs. #2 (MD = -1.6 bpm; ns) HR: #1b vs. #2 (MD = +9.2 bpm; $p < 0.05$) ↑ Adrenaline: #1a vs. #2 (MD = -0.4 ng/min; ns) Adrenaline: #1b vs. #2 (MD = -2.0 ng/min; $p < 0.05$) ↓ Noradrenaline: #1a vs. #2 (MD = +2.9 ng/min; ns) Noradrenaline: #1b vs. #2 (MD = +5.3 ng/min; $p < 0.05$) ↑ %VO2max: #1a vs. #2 (MD = -3.1; $p < 0.05$) ↓ RPE: #1a vs. #2 (MD = +10.8; $p < 0.05$) ↑ RPE: #1b vs. #2 (MD = -0.8; $p < 0.05$) ↓ RPF: #1a vs. #2 (MD = +0.1; ns) RPF: #1b vs. #2 (MD = -0.8; ns) RPA: #1a vs. #2 (MD = +0.6; ns) RPA: #1b vs. #2 (MD = -0.6; ns) RPT (MD = +0.5; ns) RPT (MD = +0.2; ns)	+	+
Möller et al. (2004)	Field study (rotation)	Operators $N = 5$	Assembly work at three workstations: assembly of indicators (a), assembly of tachometers (b), final assembly (c) (about 2.5h)	# 1: no rotation (workstation a, b, or c) (less variation) # 2: rotation (balanced across work stations a, b, and c) (more variation)	<i>All objective variables, %time at which muscle activity is >20%RVE (level) or >1s in same exposure (frequency)</i> EMG level EVA R. UT: #1a vs. #2 (MD = +0.1 %CT; ns) EMG level EVA L. UT: #1a vs. #2 (MD = -1.3 %CT; ns) EMG level EVA R. UT (L. UT: #1b vs. #2 (MD = -6.2 %CT; ns) EMG level EVA R. UT (L. UT: #1c vs. #2 (MD = +6.7 %CT; ns) EMG frequency EVA R. UT (L. UT: #1ab vs. #2 (MD = +4.6 %CT; ns) EMG frequency EVA R. UT: #1c vs. #2 (MD = -9.0 %CT; $p < 0.02$) ↓ EMG frequency EVA L. UT: #1c vs. #2 (MD = -9.8 %CT; ns)	o	n.a.
Ólafsdóttir and Rafnsson (1998)	Field study (rationalisation)	Workers $N = 176$ (pre); $N = 323$ (post)	Fish filleting (experience, no time duration)	# 1: no flow-line industry (more variation) # 2: flow-line industry (less variation)	Prevalence of shoulder complaints: Last 7 days (decrease, n.s.) Last 12 months (increase, n.s.)	o	n.a.
Palmerud et al. (2012)	Lab study (rationalisation)	Professional operators $N = 6$	Producing large diesel engines and focusing on the manual final assembly operations (a working day)	# 1 (OLD system): parallel flow long-cycle production system, whole operation by 1 person (more variation) # 2 (NEW system): conventional serial flow system, only 1 task per person (less variation)	HRR (MD = +13 %; $p < 0.001$) ↑	-	n.a.
Parenmark, Malmkvist and Ortengren (1993)	Field study (rationalisation)	Assembly workers $N = 15$ (OLD); $N = 25$ (NEW)	Assembling chain saws (working day)	# 1 (OLD system): 8 work tasks, 15 workplaces (less variation) # 2 (NEW system): 8 work tasks, 20 workplaces (more variation)	None of the parameters is tested on significance Sick leave (MD = -20%)	o	n.a.

Rissén et al. (2002)	Field study (rotation)	Cashiers $N = 31$	Cash register work work at different departments (tasks e.g. unpacking of goods, placing commod- ities on shelves, answer- ing questions) in the supermarket (2 h)	# 1: no rotation (less variation) # 2: rotation (40% at checkout counter, 60% in different departments) (more variation)	Mean EMG ARV R. UT (MD = -11 %RVE; ns) Mean EMG ARV L. UT (MD = -53 %RVE; $p < 0.01$) ↓ EMG ARV R.UT 10–50–90th% (MD = -11 %RVE; ns) EMG ARV L.UT 10–50th% (MD = -39 %RVE; $p < 0.01$) ↓ EMG ARV L.UT 90th% (MD = -76 %RVE; $p < 0.05$) ↓ EMG rest L. UT & R. UT (MD = +4 %time; ns) HR (MD = +0.6 bpm; ns) SBP (MD = +2.4 mmHg; ns) DBP (MD = -2.5 mmHg; $p = 0.05$) ↓ Positive arousal (MD = -0.8; $p < 0.05$) ↓ Negative arousal (MD = -0.2; ns) Pain experience (MD = -28%; $p < 0.05$) ↓ EMG (LaT) gaps: #1 vs. #2–3–5 (MD = +5.6 #/min, $p < 0.01$) ↑ EMG (LaT) gaps: #1 vs. #4 (MD = +0.2 #/min, ns) EMG (LaT) RMS: #1 vs. #2–3–5 (MD = -0.5 %/min, $p < 0.01$) ↓ EMG (LaT) RMS: #1 vs. #4 (MD = -7.1 %/min; ns) EMG (LaT) MnPF: #1 vs. #2–3–4 (MD = +4.6 %/min, ns) EMG (LaT) MnPF: #1 vs. #5 (MD = +6.2 %/min, $p < 0.01$) ↑ EMG (LaT) MdPF: #1 vs. #2–4–5 (MD = +4.0 %/min, ns) EMG (LaT) MdPF: #1 vs. #3 (MD = -0.4 %/min, ns) EMG (MeT) gaps: #1 vs. #2–3–4–5 (MD = +4.1 #/min, $p < 0.01$) ↑ EMG (MeT) RMS: #1 vs. #2–3–4–5 (MD = -5.6 %/min, $p < 0.01$) ↓ EMG (MeT) MnPF: #1 vs. #2–5 (MD = +6.2 %/min, $p < 0.01$) ↑ EMG (MeT) MnPF: #1 vs. #3–4 (MD = +4.4 %/min, ns) EMG (MeT) MdPF: #1 vs. #2–5 (MD = +6.0 %/min, $p < 0.01$) ↑ EMG (MeT) MdPF: #1 vs. #3–4 (MD = +3.4 %/min, ns) MMG (MeT) RMS: #1 vs. #2–3–4–5 (MD = -7.6 %/min, $p < 0.01$) ↓ MMG (MeT) MnPF: #1 vs. #2–3–4–5 (MD = +3.5 %/min, ns) MMG (MeT) MdPF: #1 vs. #2–3–5 (MD = +3.9 %/min, ns) MMG (MeT) MdPF: #1 vs. #4 (MD = -3.8 %/min, ns) Mean blood velocity: #1 vs. #2–3–5 (MD = +56.8 %; $p < 0.01$) ↑ Mean blood velocity: #1 vs. #4 (MD = +20.2 %; ns) HR: #1 vs. #2 (MD = -10.3 %/min; $p < 0.01$) ↓ HR: #1 vs. #3–5 (MD = -10.5 %/min; ns) HR: #1 vs. #4 (MD = +0.4 %/min; ns) MVC: #1 vs. #2–3–5 (MD = +8.8 %; $p < 0.01$) ↑ MVC: #1 vs. #4 (MD = +3.2 %; ns) ET: #1 vs. #2–3–5 (MD = +2423 s; $p < 0.01$) ↑ ET: #1 vs. #4 (MD = +895 s; ns) RPE: #1 vs. #2–3–4–5 (MD = -10.2 %/min; $p < 0.01$) ↓	+	+	o
Yung, Mathias- sen, and Wells (2012)	Lab study (rotation)	Adolescents $N = 15$	Sustained isometric elbow extensions (70 min)	# 1: sustained 15 %MVC (less variation) # 2: intermittent rotation 0– 30 %MVC (more variation) # 3: intermittent rotation 1– 29 %MVC (more variation) # 4: intermittent rotation 7.5–22.5 %MVC (more variation) # 5: intermittent sinusoidal rotation 0–30 %MVC (more variation)	EMG (LaT) gaps: #1 vs. #2–3–5 (MD = +5.6 #/min, $p < 0.01$) ↑ EMG (LaT) gaps: #1 vs. #4 (MD = +0.2 #/min, ns) EMG (LaT) RMS: #1 vs. #2–3–5 (MD = -0.5 %/min, $p < 0.01$) ↓ EMG (LaT) RMS: #1 vs. #4 (MD = -7.1 %/min; ns) EMG (LaT) MnPF: #1 vs. #2–3–4 (MD = +4.6 %/min, ns) EMG (LaT) MnPF: #1 vs. #5 (MD = +6.2 %/min, $p < 0.01$) ↑ EMG (LaT) MdPF: #1 vs. #2–4–5 (MD = +4.0 %/min, ns) EMG (LaT) MdPF: #1 vs. #3 (MD = -0.4 %/min, ns) EMG (MeT) gaps: #1 vs. #2–3–4–5 (MD = +4.1 #/min, $p < 0.01$) ↑ EMG (MeT) RMS: #1 vs. #2–3–4–5 (MD = -5.6 %/min, $p < 0.01$) ↓ EMG (MeT) MnPF: #1 vs. #2–5 (MD = +6.2 %/min, $p < 0.01$) ↑ EMG (MeT) MnPF: #1 vs. #3–4 (MD = +4.4 %/min, ns) EMG (MeT) MdPF: #1 vs. #2–5 (MD = +6.0 %/min, $p < 0.01$) ↑ EMG (MeT) MdPF: #1 vs. #3–4 (MD = +3.4 %/min, ns) MMG (MeT) RMS: #1 vs. #2–3–4–5 (MD = -7.6 %/min, $p < 0.01$) ↓ MMG (MeT) MnPF: #1 vs. #2–3–4–5 (MD = +3.5 %/min, ns) MMG (MeT) MdPF: #1 vs. #2–3–5 (MD = +3.9 %/min, ns) MMG (MeT) MdPF: #1 vs. #4 (MD = -3.8 %/min, ns) Mean blood velocity: #1 vs. #2–3–5 (MD = +56.8 %; $p < 0.01$) ↑ Mean blood velocity: #1 vs. #4 (MD = +20.2 %; ns) HR: #1 vs. #2 (MD = -10.3 %/min; $p < 0.01$) ↓ HR: #1 vs. #3–5 (MD = -10.5 %/min; ns) HR: #1 vs. #4 (MD = +0.4 %/min; ns) MVC: #1 vs. #2–3–5 (MD = +8.8 %; $p < 0.01$) ↑ MVC: #1 vs. #4 (MD = +3.2 %; ns) ET: #1 vs. #2–3–5 (MD = +2423 s; $p < 0.01$) ↑ ET: #1 vs. #4 (MD = +895 s; ns) RPE: #1 vs. #2–3–4–5 (MD = -10.2 %/min; $p < 0.01$) ↓	+	+	o

The conclusion in the last column is based on the significant outcomes and divided into two groups of parameters: objective (O) and subjective (S). The symbols indicate whether the particular group of parameters was predominantly positively ('+') or not significantly or equally positively and negatively ('o') affected by more activity variation.

Abbreviations: MVE, maximum voluntary electrical activity; APDF, amplitude probability distribution function; EVA, exposure variation analysis; HR, heart rate; MSPD, musculoskeletal pain disorders; EMG amplitude is expressed as the average rectified value (ARV) or root mean square (RMS); MMG amplitude is expressed as the RMS; EMG and MMG frequency are expressed as the mean (MnPF) or median (MdPF) power frequency; DSI, Dimitrov spectral index; RVE, sub-maximal reference contraction; RPD, rating of perceived discomfort; RPE, rating of perceived exertion; HRR, heart rate ratio; RPF, rating of perceived fatigue; VO2max, maximum oxygen uptake; RPA, rating of perceived activeness; RPT, rating of perceived tenderness; SBP, systolic blood pressure; DBP, diastolic blood pressure.

^aMuscles are specified between brackets right after the response variable: TR, whole M. Trapezius; R. UT, right M. Trapezius Descendens; L. UT, left M. Trapezius Descendens; R. INF, right M. Infraspinatus; R. MeD, right M. Deltoid Medialis; AD, M. Deltoid Anterior; LaT, M. Triceps Lateralis; MeT, M. Triceps Medialis.

^bAll results with the mean difference (MD) and associated p -value are presented. When the MD was not given in the original article, it is noted as 'n.d.' (not defined); significance levels higher than .05 are noted as 'ns' (not significant).

effect that an increased level of temporal or activity variation had on the objective and subjective outcomes of each study. Here, a ‘+’ indicates that more variation had a predominantly positive effect, determined as the percentage of the significant outcome parameters that was found to be positive. Similarly, a ‘–’ indicates that more variation had a predominantly negative effect and an ‘o’ indicates that more variation had no significant effect or equal significant positive and negative effects on the overall group of outcomes.

3.1 Temporal variation

In the three studies found, temporal variation was achieved by varying CT at constant DC across conditions. Hereby, the overall amount of work and the pause time were constant across conditions. The CT varied from 10 to 360 s, where conditions with a shorter CT represented conditions of more temporal variation. The task performed in all three studies concerned the isolated movement of shoulder abduction, performed for 1 h maximum. The study of Iridiastadi and Nussbaum (2006) included eight conditions, of which we made two groups of low CT versus high CT (see Table 1). These two groups showed on average no differences in DC.

The objective responses analysed in these studies included measures of amplitude and frequency of electromyography (EMG), measures of heart rate (HR), blood pressure (BP), ET and force during maximal voluntary exertion (MVE; see Table 1). None of the studies showed an effect of variation on objective manifestations of muscle fatigue in the EMG signal, as a combination of amplitude decrease and frequency increase, or the opposite pattern. In one study, only one of these changes occurred (Iridiastadi and Nussbaum 2006) and in another study both changes comprised a decrease (Yassierli and Nussbaum 2007). Furthermore, more variation led to a significant decrease in MVE (Yassierli and Nussbaum 2007) and BP (Mathiassen 1993). Regarding ET, two studies found an increase with more temporal variation (Mathiassen 1993; Yassierli and Nussbaum 2007), and the third study found no significant effect (Iridiastadi and Nussbaum 2006).

In the three studies on temporal variation, subjective experiences of discomfort or fatigue were measured. Yassierli and Nussbaum (2007) showed a decrease in the rating of discomfort. Mathiassen (1993) found a comparable but not significant change in the rating of fatigue (see Table 1). Iridiastadi and Nussbaum (2006) did not find an effect of variation on discomfort.

3.2 Activity variation

In the studies reviewed ($N = 14$), changing levels of activity variation were achieved by the implementation of task rotation or by rationalisation of the work processes. It is generally assumed that rationalisation, which seeks to improve production flow and use work time more efficiently, would lead to less variation, but we observed that rationalisation may also lead to more variation. Both rotation and rationalisation were realised by combining different movement or force patterns with each other. A summary of these findings, including a distribution between rotation and rationalisation (column 2) can be found in Table 2.

3.2.1 Rotation

The objective responses analysed in the rotation studies ($N = 7$) included measures of amplitude and frequency of EMG and mechanomyography (MMG) and measures of HR, BP, adrenaline and noradrenaline, maximal voluntary contraction (MVC), blood velocity and ET (see Table 2). Only one study found objective evidence for affected manifestations of muscle fatigue in the EMG signals, as deduced from a combination of a frequency increase and an amplitude decrease (Yung, Mathiassen, and Wells 2012). In the other studies, only one of these changes occurred or no significant changes were observed at all (Keir, Sanei, and Holmes 2011; Möller et al. 2004; Rissén et al. 2002). Horton, Nussbaum, and Agnew (2012) presented contradictory results as the EMG amplitude both increased and decreased as a result of activity variation. Two studies showed a significant decrease of HR with more variation (Kuijer, Visser, and Kemper 1999; Yung, Mathiassen, and Wells 2012) and one study showed the opposite (Kuijer et al. 2004). More variation further led to a decreased diastolic BP (Rissén et al. 2002), MMG root mean square (RMS; Yung, Mathiassen, and Wells 2012), and adrenaline concentration (Kuijer et al. 2004). Increased variation also led to an increased level of noradrenaline (Kuijer et al. 2004), MVC, mean blood velocity and ET (Yung, Mathiassen, and Wells 2012).

Subjective measurements were included in six rotation studies. Four studies (Kuijer, Visser, and Kemper 1999; Kuijer et al. 2004; Rissén et al. 2002; Yung, Mathiassen, and Wells 2012) showed significant decreases of fatigue, exertion, positive arousal and pain experience as a result of more variation (see Table 2). Two rotation studies showed contradictory results within their study, with more variation discomfort and exertion both significantly increased and decreased (Horton, Nussbaum, and Agnew 2012; Keir, Sanei, and Holmes 2011).

3.2.2 Rationalisation

The objective responses analysed in the rationalisation studies ($N = 7$) included measures of HR and measures of EMG amplitude and frequency (see Table 2). None of the studies showed that variation had an effect on objective manifestations of muscle fatigue in the EMG signal, as a combination of amplitude decrease and frequency increase, or the reverse. In two other studies, only one EMG change occurred with more activity variation (Arvidsson et al. 2012; Balogh et al. 2006). More activity variation led to an increased prevalence of musculoskeletal disorders (Christmansson, Friden, and Sollerman 1999) and HR (Palmerud et al. 2012). Two studies were not able to show significant results (Bao, Mathiassen, and Winkel 1996; Olafsdottir and Rafnsson 1998) and one study did not apply statistical analyses on its data (Parenmark, Malmkvist, and Ortengren 1993).

4. Discussion

In this review, we examined the effects of both temporal and activity variation on objective and subjective responses. To be able to investigate these effects, we selected experimental lab and field studies according to strict inclusion criteria. From the three studies on temporal variation, we concluded that more temporal variation (induced by shorter CTs) has a positive or no effect on the objective and subjective parameters. We found that the significant effects of activity variation were not convincing which made us conclude that the effects of activity variation on the outcome parameters are ambiguous.

4.1 Temporal variation

Temporal variation was the result of shortening CT which ensured that periods of continuous work were interrupted more frequently. Consequently, the more frequent interruptions may have prevented the muscle from getting fatigued. Therefore, at increased temporal variation, we expected fewer manifestations of muscle fatigue in the EMG signal (lower amplitude and higher frequency), lower BP, lower HR, longer ET and lower perceived discomfort. The two groups of low versus high CT in the study of Iridiastadi and Nussbaum (2006) showed on average no differences in DC and intensity, which made it possible for us to relate the outcomes of this study to temporal variation.

With respect to the manifestations of muscle fatigue in the EMG signal, none of the studies demonstrated a combination of amplitude decrease and frequency increase. In only one study, we observed the expected amplitude decrease (Yassierli and Nussbaum 2007). Remarkably, this was accompanied by a frequency decrease, instead of the expected frequency increase. The other two studies did not find any effect corresponding to the expected decrease in manifestations of muscle fatigue (Iridiastadi and Nussbaum 2006; Mathiassen 1993). Our expectation that subjects could longer maintain the work task with more temporal variation (shorter CTs) was confirmed (Mathiassen 1993; Yassierli and Nussbaum 2007). Besides a drop in fatigue, an increased ET could also be the result of more frequent interruptions (shorter CTs) leading to higher motivation and the ability to maintain work for a longer time period. The third study of Iridiastadi and Nussbaum (2006) also found an increased ET as a result of more temporal variation, but this was not significant.

Regarding the subjective perceptions of fatigue or discomfort, our expectation was confirmed in one study (Yassierli and Nussbaum 2007). They found a drop of 1.8 on the CR-10 Borg scale in the condition with more variation (shorter CT). Mathiassen (1993) found a decrease of 2.3 on the same CR-10 Borg scale, but this was not significant, which might be due to the low sample size ($N = 6$). The drops could be explained by less muscle fatigue, although not demonstrated in the EMG signal, or by a psychological mechanism: more temporal variation (less monotony) might be attractive to subjects and therefore result in higher motivation and work satisfaction (Bongers et al. 2006). In the third study, no effect of variation on perception of discomfort was found (Iridiastadi and Nussbaum 2006). This could be due to the intensity of the work task (10–30% MVC) which was somewhat lower than the intensity of the tasks in the other two studies (15–40% MVC).

In summary, we found some positive effects of temporal variation on subjective perceptions, but not on manifestations of muscle fatigue in the EMG signal. This inconsistency might be explained by the shoulder girdle being very complex which makes it difficult to measure whether a muscle gets fatigued or is co-activated to assist a movement (Iridiastadi and Nussbaum 2006). For example, one would expect that the M. Deltoid Medialis is the prime mover in shoulder abductions (De Luca 1997; Yassierli and Nussbaum 2007), although other muscles such as the M. Trapezius and M. Infraspinatus, are likely to be involved.

4.2 Activity variation

Activity variation was applied by rotation or rationalisation, and more activity variation in these studies created more alternations between work tasks. The greater diversity of work tasks might have prevented muscle fatigue. We expected that applying more activity variation would lead to fewer manifestations of muscle fatigue in the EMG signal (lower amplitude

and higher frequency), lower HR, lower BP and lower perceived discomfort. The results from the studies on activity variation showed ambiguous effects on the outcome parameters.

4.2.1 Rotation

One factor hampering the interpretation of the study results is the fact that in part of the studies the work intensity was not constant across conditions. From the work descriptions in the respective articles, we deduced that the intensity was not constant across conditions in the studies of Horton, Nussbaum, and Agnew (2012), Keir, Sanei, and Holmes (2011), Kuijer, Visser, and Kemper (1999) and Kuijer et al. (2004). Therefore, we initially concentrated on the other studies where such an intensity change did not occur.

With respect to the manifestations of muscle fatigue in the EMG signal, one study confirmed our expectation about a decrease in the objective manifestation of muscle fatigue due to more activity variation (Yung, Mathiassen, and Wells 2012). Möller et al. (2004) showed a significantly increased frequency in the right M. Trapezius despite their small sample size ($N = 5$). This effect might be due to the higher sensitivity that EMG frequency has over EMG amplitude or due to a higher environmental temperature.

Regarding the subjective perception of, that is arousal and pain, Rissén et al. (2002) showed contrasting results: with more activity variation, the pain experience of subjects decreased as expected, but positive arousal decreased unexpectedly. It is possible that the employees were not satisfied about the job rotation, as the tasks differed quite a lot from each other, including cash register work and stocking shelves. The study of Yung, Mathiassen, and Wells (2012) confirmed our expectation that rating of perceived exertion decreased as a result of more activity variation.

In practice, task variation is often accompanied by a change in average task intensity. Whether this is good or bad could be debated. In the studies where intensity changed along with the introduction of variation, people who normally only performed high-intensity work benefited from the introduction of variation. This was mainly reflected in their subjective feelings (Horton, Nussbaum, and Agnew 2012; Keir, Sanei, and Holmes 2011; Kuijer, Visser, and Kemper 1999; Kuijer et al. 2004). On the contrary, people who normally performed only light-intensity work deteriorated after the introduction of task rotation, as reflected in the HR and subjective feelings, among others (Horton, Nussbaum, and Agnew 2012; Keir, Sanei, and Holmes 2011; Kuijer et al. 2004). Regarding the additional effect of changed intensity, we agree with the statement of Raina and Dickerson (2009): regarding two tasks of different muscular demand, the positive decrease in muscular exposure may, to a greater extent, be the result of task rotation than solely of the task being more demanding. The benefit of task rotation might be even higher than the effort it takes to move from solely the less demanding task to a design with rotation. This implies that rotation, despite changes in task intensity, is beneficial.

4.2.2 Rationalisation

With respect to manifestations of muscle fatigue in the EMG signal, none of the rationalisation studies included EMG frequency measures. Therefore, none of these studies were able to show an effect on EMG manifestations of fatigue. The general absence of any significant effect on the EMG parameters might have been the result of the relatively short task duration (± 30 min; see Table 2) (Balogh et al. 2006; Bao, Mathiassen, and Winkel 1996). This would indicate that sufficiently long sample duration is needed to reduce exposure bias and find significant effects, as has already been suggested (Mathiassen and Svendsen 2009). Furthermore, EMG might not be sufficiently sensitive to fatigue when exertion levels are typically below 30% MVC (Horton, Nussbaum, and Agnew 2012; Movahed et al. 2011; Sood, Nussbaum, and Hager 2007; Yassierli et al. 2007). This could be the result of the absence of physiological changes within the muscles, such as rotating motor units or additional motor recruitment. However, it might merely be the result of postural changes which affect muscle activation and mask subtle physiological changes occurring due to fatigue (De Luca 1997). To get a deeper insight into the whole muscle and perhaps even in the relation between kinematics and muscle activation, using multichannel EMG over bipolar EMG might be a deliberate choice.

Two studies included HR, and only one showed that it increased with more activity variation in contrast to our expectation (Palmerud et al. 2012). Although the old organisation of the system in this study involved more variation, the new design offered improved working conditions (see Table 2) which might explain the effects on HR. Prevalence of musculoskeletal pain disorders was the outcome parameter in the study of Christmansson, Friden and Sollerman (1999) who showed that more variation leads to an increased prevalence. Apparently, the goal of the redesign here was not fulfilled, which might be due to the increased age of the employees during the long follow-up period. Another explanation might be that the redesigned jobs had too much variation which did not meet the assemblers' competences and skills. Bao, Mathiassen, and Winkel (1996) did not find significant effects of more variation on any of the objective parameters which might be due to the pre- and post-groups that differed both in number and composition. The same reasoning applies to the study of Olafsdottir and Rafnsson (1998).

In summary, the observed effects of activity variation are ambiguous. No final conclusion can be drawn. This can be explained by the fact that most studies have not controlled for the amount or intensity of work. Remarkably, the highly controlled laboratory study of Yung, Mathiassen, and Wells (2012) showed positive effects.

Regarding the limited number of studies that we found, the question remains whether we missed relevant articles. Therefore, we also searched within the database Scopus, but we did not find additional relevant articles. Finally, two articles were added from personal databases of the authors. Reasons for missing these particular articles were because one of the articles was presented in Icelandic only on Pubmed and in the other article no keyword with respect to the shoulder was provided although three out of the five keywords were covered in our search terms. From this, we have decided to hold on to our current search strategy.

5. Conclusion

Task variation is widely advocated as a means to lower the impact of loads on the shoulder region in repetitive hand–arm tasks. With respect to temporal variation, we indeed found some positive effects on the objective measurements as BP decreased and ET increased, and on the subjective measurements as feelings of perceived discomfort decreased. However, the main part of the objective outcome measurements included EMG parameters, which did not show effects on the manifestations of muscle fatigue. This might be explained by the fact that EMG only reflects a small part of the physiological state of the muscle (Bosch 2011) while postural changes affect muscle activation masking subtle changes occurring due to fatigue (De Luca 1997). Replacing bipolar EMG with multichannel EMG might be worth considering in this respect. Regarding activity variation, the observed findings showed ambiguous effects, which might be due to the fact that the outcomes were not controlled for the amount or intensity of work. Therefore, we were not able to draw a conclusion concerning the effect of activity variation. Especially, the studies where task intensity changed as well, positive effects were found when rotation was introduced to tasks solely consisting of high muscular demands.

6. Practical implications

Increasing temporal variation showed some positive effects on the studied outcome parameters, which resulted from laboratory studies on isolated isometric activities. This gives limited support for the introduction in real life settings by applying more frequent interruptions in rather monotonous work (assembly work, pick and place work or packing work). However, whether increasing task variation in practice would indeed lead to decreased fatigue, better subjective feelings and consequently fewer health problems, needs to be validated.

Evidence is lacking for the implementation of activity variation into practice. This does not necessarily mean one must renounce it. Although activity variation is assumed to result in a more complete but also complex job, resulting in higher motivation, lower monotony and subsequently lower task aversion (Kuijer, Visser, and Kemper 1999), when applying it into practice needs consideration. One should take into account several factors: the nature of the work to be performed, the competencies and skills of the employees, an ample collection of diversified tasks, acceptance by the management and the workers, and financial resources (Allwood and Lee 2004; Balogh et al. 2006; Christmansson, Friden, and Sollerman 1999).

All in all, temporal variation could be applied by introducing more frequent interruptions. It would be a challenge for practice to implement it, because a lot of occupational work is not as monotonous as the character of the experimental tasks in the studies included. Activity variation effects were ambiguous and evidence is lacking to recommend its implementation into practice. However, the lack of evidence does not necessarily mean that implementation of activity variation into practice should be renounced. However, when deciding to implement and evaluate any type of task variation into existing occupational work schedules, one should be aware of the amount of natural variation already present in tasks as these generally do not solely consist of one single movement. Furthermore, applying variation in general will certainly be accompanied by fluctuations of average task intensity, which might be undesirable but unavoidable and not necessarily bad for the employee.

Acknowledgements

The authors would like to thank Svend Erik Mathiassen and Divya Srinivasan from the University of Gävle (Sweden) for their valuable input.

Notes

1. Email: tim.bosch@tno.nl
2. Email: h.e.j.veeger@vu.nl
3. Email: michiel.delooze@tno.nl

References

- Allwood, J. M., and W. L. Lee. 2004. "The Impact of Job Rotation on Problem Solving Skills." *International Journal of Production Research* 42 (5): 865–881.
- Andersen, J. H., A. Kaergaard, P. Frost, J. F. Thomsen, J. P. Bonde, N. Fallentin, V. Borg, and S. Mikkelsen. 2002. "Physical, Psychosocial, and Individual Risk Factors for Neck/Shoulder Pain with Pressure Tenderness in the Muscles Among Workers Performing Monotonous, Repetitive Work." *Spine* 27 (6): 660–667.
- Arvidsson, I., I. Balogh, G. A. Hansson, K. Ohlsson, I. Akesson, and C. Nordander. 2012. "Rationalization in Meat Cutting – Consequences on Physical Workload." *Applied Ergonomics* 43 (6): 1026–1032.
- Balogh, I., K. Ohlsson, G. A. Hansson, T. Engstrom, and S. Skerfving. 2006. "Increasing the Degree of Automation in a Production System: Consequences for the Physical Workload." *International Journal of Industrial Ergonomics* 36 (4): 353–365.
- Bao, S. H., S. E. Mathiassen, and J. Winkel. 1996. "Ergonomic Effects of a Management-Based Rationalization in Assembly Work – A Case Study." *Applied Ergonomics* 27 (2): 89–99.
- Bongers, P. M., S. Ijmker, S. van den Heuvel, and B. M. Blatter. 2006. "Epidemiology of Work Related Neck and Upper Limb Problems: Psychosocial and Personal Risk Factor (Part I) and Effective Interventions from a Bio Behavioural Perspective (Part II)." *Journal of Occupational Rehabilitation* 16 (3): 279–302.
- Bosch, T. 2011. "Fatigue and Performance in Repetitive Industrial Work." PhD diss., VU University, Amsterdam.
- Christmannson, M., J. Friden, and C. Sollerman. 1999. "Task Design, Psycho-social Work Climate and Upper Extremity Pain Disorders – Effects of an Organisational Redesign on Manual Repetitive Assembly Jobs." *Applied Ergonomics* 30 (5): 463–472.
- De Luca, C. J. 1997. "The Use of Surface Electromyography in Biomechanics." *Journal of Applied Biomechanics* 13 (2): 135–163.
- Grooten, W. J. A., C. Wiktorin, L. Normann, M. Josephson, E. W. Tornqvist, and L. Alfredsson. 2004. "Seeking Care for Neck/Shoulder Pain: A Prospective Study of Work-Related Risk Factors in a Healthy Population." *Journal of Occupational and Environmental Medicine* 46 (2): 138–146.
- Hagberg, M., and G. Sundelin. 1986. "Discomfort and Load on the Upper Trapezius Muscle When Operating a Word Processor." *Ergonomics* 29 (12): 1637–1645.
- Henning, R. A., P. Jacques, G. V. Kissel, A. B. Sullivan, and S. M. AlterasWebb. 1997. "Frequent Short Rest Breaks from Computer Work: Effects on Productivity and Well-being at Two Field Sites." *Ergonomics* 40 (1): 78–91.
- Horton, L. M., M. A. Nussbaum, and M. J. Agnew. 2012. "Effects of Rotation Frequency and Task Order on Localised Muscle Fatigue and Performance During Repetitive Static Shoulder Exertions." *Ergonomics* 55 (10): 1205–1217.
- Iridiastadi, H., and M. A. Nussbaum. 2006. "Muscle Fatigue and Endurance During Repetitive Intermittent Static Efforts: Development of Prediction Models." *Ergonomics* 49 (4): 344–360.
- Keir, P. J., K. Sanei, and M. W. R. Holmes. 2011. "Task Rotation Effects on Upper Extremity and Back Muscle Activity." *Applied Ergonomics* 42 (6): 814–819.
- Kuijer, P. F. M., W. H. K. de Vries, A. J. van der Beek, J. H. van Dieen, B. Visser, and M. H. W. Frings-Dresen. 2004. "Effect of Job Rotation on Work Demands, Workload, and Recovery of Refuse Truck Drivers and Collectors." *Human Factors* 46 (3): 437–448.
- Kuijer, P., B. Visser, and H. C. G. Kemper. 1999. "Job Rotation as a Factor in Reducing Physical Workload at a Refuse Collecting Department." *Ergonomics* 42 (9): 1167–1178.
- Kuijpers, T., D. A. W. M. van der Windt, G. J. M. G. van der Heijden, J. W. R. Twisk, Y. Vergouwe, and L. M. Bouter. 2006. "A Prediction Rule for Shoulder Pain Related Sick Leave: A Prospective Cohort Study." *BMC Musculoskeletal Disorders* 6 (7): 97.
- Luime, J. J., J. I. Kuiper, B. W. Koes, J. A. N. Verhaar, H. S. Miedema, and A. Burdorf. 2004. "Work-Related Risk Factors for the Incidence and Recurrence of Shoulder and Neck Complaints Among Nursing-Home and Elderly-Care Workers." *Scandinavian Journal of Work, Environment & Health* 30 (4): 279–286.
- Mathiassen, S. E. 1993. "The Influence of Exercise/rest Schedule on the Physiological and Psychophysical Response to Isometric Shoulder–Neck Exercise." *European Journal of Applied Physiology and Occupational Physiology* 67 (6): 528–539.
- Mathiassen, S. E. 2006. "Diversity and Variation in Biomechanical Exposure: What Is It, and Why Would We Like to Know?" *Applied Ergonomics* 37 (4): 419–427.
- Mathiassen, S., and S. Svendsen. 2009. "Systematic and Random Errors in Posture Percentiles Assessed from Limited Exposure Samples." Paper presented at 17th Congress of the IEA, Beijing, China, August 9–14.
- Movahed, M., J. Ohashi, N. Kurustien, H. Izumi, and M. Kumashiro. 2011. "Fatigue Sensation, Electromyographical and Hemodynamic Changes of Low Back Muscles During Repeated Static Contraction." *European Journal of Applied Physiology* 111 (3): 459–467.
- Möller, T., S. E. Mathiassen, H. Franzon, and S. Kihlberg. 2004. "Job Enlargement and Mechanical Exposure Variability in Cyclic Assembly Work." *Ergonomics* 47 (1): 19–40.
- Olafsdottir, H., and V. Rafnsson. 1998. "Increase in Musculoskeletal Symptoms of Upper Limbs Among Women After Introduction of the Flow-line in Fish-fillet Plants." *International Journal of Industrial Ergonomics* 21 (1): 69–77.
- Palmerud, G., M. Forsman, W. P. Neumann, and J. Winkel. 2012. "Mechanical Exposure Implications of Rationalization: A Comparison of Two Flow Strategies in a Swedish Manufacturing Plant." *Applied Ergonomics* 43 (6): 1110–1121.
- Parenmark, G., A.-K. Malmkvist, and R. Ortengren. 1993. "Ergonomic Moves in an Engineering Industry: Effects on Sick Leave Frequency, Labor Turnover and Productivity." *International Journal of Industrial Ergonomics* 11: 291–300.
- Raina, S. M., and C. R. Dickerson. 2009. "The Influence of Job Rotation and Task Order on Muscle Fatigue: A Deltoid Example." *Work – A Journal of Prevention Assessment & Rehabilitation* 34 (2): 205–213.
- Rissén, D., B. Melin, L. Sandsjö, I. Dohms, and U. Lundberg. 2002. "Psychophysiological Stress Reactions, Trapezius Muscle Activity, and Neck and Shoulder Pain Among Female Cashiers Before and After Introduction of Job Rotation." *Work & Stress* 16 (2): 127–137.
- Samani, A., A. Holtermann, K. Sogaard, and P. Madeleine. 2009. "Active Pauses Induce More Variable Electromyographic Pattern of the Trapezius Muscle Activity During Computer Work." *Journal of Electromyography and Kinesiology* 19 (6): e430–e437.

- Sood, D., M. A. Nussbaum, and K. Hager. 2007. "Fatigue During Prolonged Intermittent Overhead Work: Reliability of Measures and Effects of Working Height." *Ergonomics* 50 (4): 497–513.
- Szeto, G. P. Y., L. M. Straker, and P. B. O'Sullivan. 2005. "A Comparison of Symptomatic and Asymptomatic Office Workers Performing Monotonous Keyboard Work – 1: Neck and Shoulder Muscle Recruitment Patterns." *Manual Therapy* 10 (4): 270–280.
- van den Heuvel, S. G., M. P. de Looze, V. H. Hildebrandt, and K. H. Thé. 2003. "Effects of Software Programs Stimulating Regular Breaks and Exercises on Work-Related Neck and Upper-Limb Disorders." *Scandinavian Journal of Work, Environment & Health* 29 (2): 106–116.
- van der Heijden, G. J. 1999. "Shoulder Disorders: A State-of-the-art Review." *Baillière's Best Practice & Research: Clinical Rheumatology* 13 (2): 287–309.
- van Rijn, R. M., B. M. A. Huisstede, B. W. Koes, and A. Burdorf. 2010. "Associations Between Work-Related Factors and Specific Disorders of the Shoulder – A Systematic Review of the Literature." *Scandinavian Journal of Work Environment & Health* 36 (3): 189–201.
- Westgaard, R. H., and J. Winkel. 1996. "Guidelines for Occupational Musculoskeletal Load as a Basis for Intervention: A Critical Review." *Applied Ergonomics* 27 (2): 79–88.
- Yassierli, M. A., and Nussbaum. 2007. "Muscle Fatigue During Intermittent Isokinetic Shoulder Abduction: Age Effects and Utility of Electromyographic Measures." *Ergonomics* 50 (7): 1110–1126.
- Yassierli, M. A., H. Nussbaum, L. A. Iridiastad, and Wojcik. 2007. "The Influence of Age on Isometric Endurance and Fatigue is Muscle Dependent: A Study of Shoulder Abduction and Torso Extension." *Ergonomics* 50 (1): 26–45.
- Yung, M., S. E. Mathiassen, and R. P. Wells. 2012. "Variation of Force Amplitude and its Effects on Local Fatigue." *European Journal of Applied Physiology* 112 (11): 3865–3879.